Open Access
J. Glob. Innov. Agric. Sci., 2023, 11(4):499-506.
ISSN (Online): 2788-4546; ISSN (Print):2788-4538
DOI: https://doi.org/10.22194/JGIAS/11.1180
http://www.jgiass.com

Society for Innovative Agiculture

Enhancing reforestation efforts: a comprehensive analysis of modern approaches to cultivate planting material for forest crops

Dmitri Borodulin[1,]* and Aleksandr Maksimenko[2]

[1]Russian State Agrarian University - Moscow Timiryazev Agricultural Academy, Moscow, st. Timiryazevskaya, 49 Russia;
[2]Kemerovo State University, Kemerovo, Russia
*Correspondence author's e-mail: dmitry.borodulin@bk.ru

The paper presents a comprehensive study of various methods and techniques used in the cultivation of planting material for reforestation purposes. This study is aimed at in-depth analysis and comparative evaluation of various approaches to the production of healthy and high-quality planting material for forest crops to increase the productivity and sustainability of reforestation practices. In the course of the study, a review of scientific literature in the field of crop production and reforestation technologies was conducted in the thematic journals indexed by Scopus, Web of Science, Elibrary, and Google Academy. The search depth was 40 years, and the search languages were English and Russian. According to the results of the study, today the method of growing seedlings with a closed root system is the most effective and dynamically developing way that can be used to solve a wide range of problems. The proposed methods of improvement are aimed at creating more economical and efficient systems for growing seedlings with a closed root system and represent the use of worked-out mines as greenhouses for growing seedlings. In addition, the use of the Internet of Things, machine learning, and neural networks will automate the process of growing seedlings, reducing human participation in this process and the risk of loss of planting material.
Keywords: Reforestation, biological cultivation, crop production technologies, modern crop production.

INTRODUCTION

The coal mining industry in Russia's Kuznetsk Basin (Kuzbass) faces environmental challenges, such as land disturbance and pollution. Reforestation is critical for mitigating these challenges by restoring damaged lands. However, any of the methods of coal mining is accompanied by the removal of land from economic circulation, the disturbance of the terrain, the formation of a man-made landscape, as well as pollution of the local biosphere. Every year, the volume of coal production increases by an average of 20%, which results in a tendency to increase the area of annually disturbed land (Kharionovskii and Danilova, 2017; Ufimtsev, 2017). Unfortunately, the growth rate of reclamation of overburden dumps is slowing down. The reason for this is the lack of special technical means of performing reclamation works, low efficiency of plant survival, as well as the lack of effective economic incentives for the restoration of disturbed lands.

Coal deposited in sedimentary rocks is mainly represented by clay, sandy, and carbonate rocks, each of which is characterized by certain physical and mechanical properties (Potapov *et al*., 2005). When it is extracted using an open method, significant masses of host rocks are stored in dumps, occupying large areas. Man-made structures of this size can carry a great danger both for all work on the section and for the environment, including working personnel. Dumps are an environmentally unfavorable structure. The main negative phenomena that occur with the appearance of a dump are dust emissions, water and wind erosion, subsidence and landslides, and spontaneous combustion. Wind erosion of the dump surface creates the issue of the increasing level of dust. Thousands of tons of dust enter the atmosphere, which includes not only toxic components but also fine dust with particle sizes of about 2.5 microns, which is a particular danger to the health of the population living nearby. As a result of rain erosion of dumps, they become sources of acidic waters that acidify adjacent territories and destroy their fertility (Chibrik, 2002; Zaushintsena and Kozhevnikov, 2015; Zharikov., 2012).

Considering the listed negative consequences caused by the processes occurring in the dumps, one can conclude that there

Borodulin, D., and A. Maksimenko. 2023. Enhancing reforestation efforts: a comprehensive analysis of modern approaches to cultivate planting material for forest crops. Journal of Global Innovations in Agricultural Sciences 11:499-506.
[Received 10 Jun 2023; Accepted 20 Oct 2023; Published 22 Dec 2023]

is a need to prevent them. The most effective solution to this problem is biological reclamation, which is based on the technology of mass cultivation of grasses, shrubs, and trees on dumps, to strengthen and fix rocks and promote biodegradation of toxic compounds contained in them (Bugubaeva *et al*., 2023). Since one of the limiting factors in the task of increasing the growth rate of reclamation is the lack of specialized technical means, the development and research of technologies in the field of biological reclamation are relevant.

The purpose of this work is to find ways to improve technologies for growing planting material for forest crops.

MATERIALS AND METHODS

***The study comprises two stages*:** a literature analysis on biological reclamation and planting material cultivation methods, followed by a search for methods to enhance planting material production:

1. In the first stage, an analysis of the literature on biological reclamation and methods and technologies for growing planting material was carried out.
2. In the second stage, based on the literature analysis, we performed a search for methods to develop and improve technologies for growing planting material.

Data analysis: We performed a literature review in the field of crop production and reforestation technologies retrieved from the thematic journals indexed by Scopus, Web of Science, Elibrary, and Google Academy. The search depth was 40 years, and the search languages were English and Russian.

RESULTS

Reclamation stages: Forest restoration is a complex of consistently built and scientifically based measures aimed at the reasonable use of forest lands, optimization of the structure of the forest by composition and age, restoration of the economic and aesthetic value of natural landscapes, and improvement of the ecological situation. Artificial forest cultivation plays an important role in reforestation (Merzlenko and Babich., 2011).

Reclamation stages in forest restoration involve a series of scientifically planned measures for the optimal use of forest lands, ecological improvement, and economic restoration of natural landscapes. In general, reforestation includes mining engineering, land reclamation, agricultural and forestry, and civil engineering works, and consists of the following stages.

The first (preparatory) stage of reclamation includes the performance of design and survey work, which involves the survey of disturbed areas (processing area, condition of slopes and dumps, properties of surface and underlying soils, etc.), assessment of the natural and climatic situation of the region, and other work aimed at geological exploration of the territory. Based on the collected information, the purpose of recultivated lands is determined, the rational focus area of recultivation is planned, and project documentation is created (Chernodubov *et al*., 2013; Yakimov *et al*., 2007).

The second stage is mining engineering reclamation, which includes the preparation of the disturbed surface for subsequent biological reclamation. This stage includes the leveling of dumps and slopes, improvement of the territory by applying a fertile soil layer, chemical treatment of contaminated soils, and various measures aimed at controlling the water regime. The terrain of the territory should be leveled, and the optimal slope should be 3-5°. Reclamation areas intended for forest use may have undulating or moderately rugged terrain, but it is necessary to consider the possibility of using mechanisms for forest work and preventing erosion. At this stage, the construction of roads and other engineering structures is also carried out, if necessary (Rodin *et al*., 2009).

The third stage is biological reclamation aimed at the final restoration of the fertility of disturbed lands. Recultivation can be done on agricultural or forest lands. In agricultural reclamation, it is envisaged to apply an arable layer of soil, which was removed before the start of work, to the flat surface of the quarry (Revyako, 2013). Before the main tillage, increased doses of organic and mineral fertilizers are applied (Nokusheva *et al*., 2023), and if necessary, liming or land plaster treatment (acidic soil alkalinization) is carried out. During the first few years, soil-improving plants such as legumes (lupine, alfalfa, clover, etc.) and perennial grasses are grown on such soils. In the following years, the main agricultural and forest crops are gradually introduced on the territory. From the point of view of technology, the last stage is the most important and technology-intensive one.

Technologies for growing forestry planting material: Since annual and perennial grasses are less volatile and more resistant to unfavorable cultivation conditions, special attention is required by the technology of growing forestry planting material.

In the world reforestation practice, a special form of forestry on industrial dumps has developed: the creation of preliminary meliorative plantings from fast-growing undemanding species and their gradual replacement with plantings from more valuable species. Reclamation species are alder, white acacia, and poplars (Prokazin *et al*., 2019). In the USA, three-stage forest reclamation is practiced, consisting of the creation of three successive groups of plantings: pioneer (white acacia, black alder), intermediate (sycamore, fast-growing poplars), and final (oak, white ash, walnut) (Mikhailova, 2008). The cultivation of these three groups in a single plantation justifies itself, as it involves some reclamation species, some fast-growing and some main forest-forming species. Then alder and acacia are gradually cut down after 16-18 years, fast-growing trees after 25-30

years, and the remaining main species are used after 45-60 years.

To date, several factors are limiting the rate of reforestation in the field of planting material cultivation.

Inefficient cultivation methods: Some traditional methods of growing planting material may be inefficient in terms of time and cost. The technologies currently used may require considerable time for cultivation and lead to low productivity and production volume of planting material (Naoshi and Ting, 1998).

Limited use of new technologies: New and innovative methods of growing planting material may be little used for reforestation due to their high cost. Insufficient adaptation of new technologies limits their implementation and impact on improving the production of planting material.

Requirements for specialized growing conditions: Some types of trees and plants for planting material may require special growing conditions, such as a certain temperature, humidity, or light. Ensuring these conditions can be difficult and costly, especially on the scale of large reforestation projects.

Lack of automation: Manual or semi-automatic processes are often used in the production of planting material for reforestation, which can reduce productivity and quality. The lack of automation limits the possibilities of increasing production volumes and improving process efficiency.

Insufficient standardization: The lack of standards in the production of planting material can lead to dissimilarity and heterogeneity of seedlings, which makes it difficult for their successful adaptation and growth after planting in forests (Ren *et al*., 2018). Standardization of cultivation technologies can significantly improve the quality and stability of planting material.

The main task of growing tree seedlings in nurseries is to create a healthy and high-quality root system, which in the future can integrate into the target biosystem and continue natural growth (Rodin *et al*., 2009). To solve this problem, researchers have created many highly effective methods and technologies that include knowledge from a variety of fields.

Sowing forest crops in the soil: One of the first methods of artificial forest cultivation is the sowing of forest crops in the soil, where we copy the technology of biologically induced reproduction of trees. In other words, the seeds are placed in the ground with the required planting density. During the growth of seedlings, they are monitored by an agronomist to take the necessary measures in case of deterioration of the condition of plants.

This method has the following advantages:

1. There is no need for the construction and maintenance of a nursery, which makes this method low-cost from the point of view of investing money.
2. Plants have a naturally developed root system. According to (Tretyakova *et al*., 2023), the total weight of the roots of planting material with an open root system averaged 52.7 g. Its biometric indicators (average plant height, phytomass, length of needles, etc.) are higher compared to planting material with a closed root system (CRS). The research was carried out on nine-year-old seedlings of Siberian stone pine.
3. The scheme of sowing operations was simple.

However, in addition to the advantages, there are disadvantages, the first and main of which is dependence on weather conditions. The optimal combination of environmentally controlled and uncontrolled factors (temperature regime, soil moisture, light intensity, and aeration, quality of tillage, and its fertility) directly affects seed germination (Curtis and David, 2003). This factor limits the use of the method. Besides, an average of 5-7 times more seeds are used during planting than when growing seedlings with a CRS.

***Method of growing seedlings with a CRS*:** The following method of growing seedlings with a CRS (forest planting) is in its way an evolutionary continuation of the previous method. The method of growing seedlings with a CRS is the process of growing plants in containers or special substrates where the roots are in a closed space (Rodin *et al*., 2009). This method has become popular in horticulture, forestry, and landscape design due to the following advantages.

1. Improved survival rate. Seedlings with CRS have the best chances of survival when replanted into a new environment due to a controlled growing environment and a preserved root system, which contributes to successful rooting (Tretyakova *et al*., 2023).
2. Extensions of the growing season. The CRS method allows for growing seedlings without reference to planting seasons. For example, the sowing of forest crops with an open root system in the target area can be carried out only in a certain season, depending on the type of plant.
3. Efficient use of space. Seedlings with CRS take up less space than their full-size counterparts, which is especially important for growing in confined spaces, such as urban gardens and greenhouses.
4. Resistance to diseases and pests. CRS seedlings can be produced in a closed and controlled environment, which reduces the risk of infection with diseases or pest attacks.
5. High adaptation rate. Since the replanting of a whole plant into the open ground is carried out together with the substrate, this method allows for restoring forests even in depleted soils, where standard sowing without long-term preparatory work with the soil will be ineffective (Tretyakova *et al*., 2023).

Most of the negative qualities of using the method of growing seedlings with a CRS are associated with its features and requirements. Many of them are a consequence of the benefits and work as a side effect. The researchers put forward the following limiting factors for the use of this method.

High costs: The introduction of the CRS method requires significant financial investments. This is due to the purchase

of special containers, substrates, irrigation systems, condition monitoring, and other equipment (Korchagov *et al*., 2017). High costs may not be available for small horticultural farms or farmers with a limited budget.

Difficulty in care: Growing seedlings with CRS requires experience and technical competence. Control over the condition of plants, optimal conditions inside containers, irrigation, and fertilizer management require care and accuracy. Improper actions can negatively affect the health of plants.

Limited size of seedlings: The CRS method is suitable primarily for young plants and seedlings. In some cases, this may limit the use of this method for growing large-sized trees or shrubs that have branched root systems (Merzlenko and Babich, 2011).

Dependence on technical systems: In addition to the complexity in the care and maintenance of factors, the CRS requires maintaining optimal conditions inside containers, which can be difficult in case of technical systems (such as irrigation, lighting, and ventilation systems) failure or malfunction.

Weakness of the root system: In some cases, seedlings with a CRS may have a weaker root system than plants grown in an open environment, which may affect the rate of formation of plant phytomass. The root system of seedlings with CRS is a dense network of intertwined roots, with a predominance of a fibrous root system. According to scientists (Tretyakova *et al*., 2023), this ensures better survival and active growth of roots when they are replanted into the target soil compared to the open root system.

Problems during replanting: Even though seedlings with CRS have a high survival rate during replanting, improper replanting techniques or stress during the transition from a controlled environment to an open environment can damage the roots and lead to problems with plant growth and development (Oliet *et al*., 2013).

DISCUSSION

Most disadvantages of the CRS method can be minimized or overcome with proper organization and cultivation techniques. This method is developing very dynamically through the introduction of modern technological solutions aimed at accelerating the growth of seedlings, the stable yield of high-quality planting material (and as a consequence, the use of standardization of seedlings), and reducing labor and financial costs for cultivating seedlings (Morkovina *et al*., 2021). According to recent studies, there are several prospects for improving technological solutions for growing seedlings with CRS.

Improvement of substrates: One of the key aspects of the CRS method is the selection of a suitable substrate for plant roots. Research is aimed at developing optimal mixtures of substrates that provide good moisture retention, air permeability, and nutritional properties that promote healthy root development. In (Vicent *et al*., 2005), the addition of a hydrogel fraction to a substrate for growing citrus fruits was researched. The data obtained showed that at a hydrogel concentration of 0.4% in the substrate, the survival rate of seedlings replanted into the soil and subjected to six cycles of induced stress as a result of soil drying, increased to 79%. This study will allow planting seedlings even in arid regions where there are problems with fresh water for irrigation.

Optimization of irrigation and fertilization: Irrigation control and fertilization of substrates are important aspects of growing seedlings with CRS. The research is aimed at determining optimal irrigation regimes and optimizing the composition of fertilizers to ensure optimal plant growth and development. One can note the joint research of Canadian and American scientists (Douglass and Vic, 2005), who studied the effect of fertilizers applied when planting seedlings on the state of the rhizosphere in the subsequent growth period. After fertilizing during replanting, it can promote the absorption of nutrients and reduce the shock during replanting. However, fertilization can dramatically change the chemical properties of the rhizosphere, such as pH, ion availability, and electrical conductivity (EC). In case of drought, there is an excess of fertilizer salts in the rhizosphere, which can lead to a deterioration in the assimilation of water and nutrients by the roots. Research in the areas of optimization of irrigation and fertilization allowed for the creation of fertilizer application programs based on the type of soil, climatic conditions of the area, the type of seedling, as well as conditions for monitoring and support of plantings.

***Automation of the growing and planting process*:** The development of technologies and automation of growing processes make it possible to improve the efficiency and accuracy of the CRS method. Automated systems of irrigation, fertilizers, and environmental control help to provide more stable conditions for plant growth (Naoshi and Ting, 1998). The use of machine learning and machine vision systems, as well as the Internet of Things (IoT), can contribute to improving the control and management of seedlings by optimizing the use of biotic and abiotic factors affecting their growth and development.

***Modification of containers*:** A change in the design of containers used for growing seedlings with CRS is also an important field of development. Modifications may include more convenient drainage systems, optimized container shapes to minimize root damage during replanting, and improved materials to increase the durability of containers. The study (McGrath *et al*., 2021) evaluated the effect of the height of containers and their shape on the quality of the root system of eastern cottonwood and cherry trees after four months of cultivation and a year after replanting. The quality of the roots was assessed in terms of the presence of large root defects. The results showed that taller containers produced a less defective root system, but there were no differences in

aboveground growth between different types of containers. the studies continue, as scientists suggest that differences in growth in seedlings with different quality of the root system may appear in a few years.

***Growing large trees and shrubs*:** The CRS method makes it possible to grow large-sized trees and shrubs with better survival during replanting. Research in this area is aimed at developing optimal technologies for growing and caring for large plants with a CRS (Ospangaliyev *et al*., 2022 and 2023).

Improving energy efficiency: In some cases, the successful cultivation of seedlings with CRS requires the creation of a controlled environment in greenhouses or greenhouses. Research is aimed at developing more energy-efficient heating and lighting methods to reduce operating costs and reduce environmental impact. A recently published paper by American scientists (Ajagekar *et al*., 2023) showed a 57% reduction in greenhouse energy consumption when using control structures based on artificial intelligence and the theory of mathematical optimization. This system combines deep learning methods with reinforcement to obtain information about the operation of the greenhouse, as well as the theory of mathematical optimization, which considers the degree of resistance to the uncertainty of forecasting climatic conditions by a neural network (NN), which ultimately will allow creating energy-efficient means of controlling the microclimate of greenhouses.

In addition to the main directions of development of the method of growing seedlings with CRS, one should also note some of the following additional aspects that are actively being investigated and developed.

***Adaptation to extreme environmental conditions*:** The CRS method allows for growing plants in conditions that were previously unsuitable for traditional gardening or agriculture. This includes growing plants in saline soils, arid areas, and mountainous areas. Research in this area is aimed at identifying plants that adapt better to extreme conditions and developing optimal methods for growing planting material capable of survival and successful growth in extreme environments (Akhmetov *et al*., 2023; Rakymbekov *et al*., 2023;Yessimbek *et al*., 2022).

Use of biotechnologies: Modern biotechnologies, such as tissue culture and genetic engineering, play an important role in the development of the CRS method. With these technologies, it is possible to massively propagate plants using microclonal propagation (Revyako., 2013), as well as to create new varieties and hybrids with increased resistance to diseases, pests, or extreme conditions (Kondratenko and Soboleva., 2023). This can include genetic engineering as one of the ways to quickly create relatively traditional methods of breeding new plant species. However, the introduction of genetic engineering methods is limited by laws and outdated regulatory documents in the fields of biotechnology, ecology, and medicine (Halford., 2019).

One should also note the development of biotechnology associated with the introduction of microbiological preparations (Bashan *et al*., 2014), which increase the productivity of plant growth, and their resistance to diseases and adverse climatic factors.

***Integration with ecosystems*:** One of the interesting directions of the development of the CRS method is its integration with natural ecosystems. This can be useful for restoring natural landscapes after fires, forest felling, or other natural disasters. Research in this area is aimed at determining the optimal plant species and methods to integrate them into ecosystems.

***Cultivation of rare and vulnerable species*:** The CRS method can be applied to the conservation and reproduction of rare and vulnerable plant species. Here research is aimed at determining the optimal conditions for the cultivation of such species and the development of programs for the conservation of biodiversity. To grow seedlings of rare species of forest crops, researchers often use another method of cultivation on mineral substrates, called hydroponics. This method allows for controlling climatic conditions and providing nutrition schemes with a high degree of accuracy, which increases the efficiency of seedlings and survival of forest crops, compared with cultivation in classical substrates. However, the use of this technology is advisable only for rare and vulnerable species since it requires large monetary and labor costs and cannot be justified yet from an economic point of view for growing the most popular seedlings on a large scale.

***Interdisciplinary research*:** The development of the CRS method requires the cooperation of various scientific disciplines, such as botany, agriculture, ecology, genetics, and engineering. Interdisciplinary research allows a deeper understanding of the mechanisms of plant growth, and their interaction with the environment and optimizes cultivation methods.

The method of growing seedlings with a CRS continues to develop and attract the attention of researchers and practitioners in agriculture and forestry. Due to its advantages and capabilities, it will continue to play an important role in improving plant production and environmental protection.

Based on the results of the study, the following improvement of the method of growing seedlings with CRS is proposed to increase its effectiveness concerning reforestation in the Kuzbass.

Some of the main consumers of seedlings for reforestation are coal industry enterprises that need to carry out work on biological reclamation of lands that have been disturbed as a result of coal production. Most of the coal production consists of underground diggings (Kuznetsova, 2008) that result in a significant amount of waste rock produced by coal mines, which is not used for industrial purposes in the future. These underground diggings can be converted into greenhouses for the cultivation of planting material for forest species. Similar experiments have already been carried out by engineers (Jans-Singh *et al*.,2019) from London, who converted bomb shelters

from the Second World War into farms for hydroponics. Conversion of the worked-out mines into greenhouses can have the following advantages:

1. Cultivation of planting material near the place of its use, to reduce the cost of its transportation.
2. The maintenance of optimal growing conditions is based on the regulation within certain limits of such parameters as illumination, temperature, humidity, and CO_2 concentration. In an isolated system of worked-out mines, maintaining the above parameters will require the use of fewer energy resources in comparison with greenhouse cultivation.
3. Underground nurseries can be used as a field for experiments due to finely tuned climatic conditions.
4. Such an underground cultivation system can be equipped with the IoT to control and regulate the parameters of the microclimate, which can be handled by both a person and a trained NN. In addition to greenhouse management, NN can also be used to select a biological reclamation strategy, in other words, to determine plant species, substrate, and containers for their cultivation for a specific type of soil and climatic conditions of the area.

***Conclusion*:** According to the results of the study, today the method of growing seedlings with CRS is the most effective and dynamically developing way, capable of solving a wide range of problems. This is possible due to the optimal ratio of the efficiency of labor and monetary costs aimed at a specific goal (reforestation).

The CRS method for growing seedlings is flexible in terms of the resources spent on reforestation most rationally. Using new knowledge from botany, we can choose the optimal substrate and microclimatic regime and apply biotechnology to create microbiological preparations aimed at increasing the survival rate of a specific forest crop in the target area in need of reforestation. The process of introducing modern technologies in forestry can be compared with personalized medicine, which selects treatment options for a specific person to increase the chance of a successful recovery.

The proposed ways of improvement are aimed at creating more economical and efficient systems for growing seedlings with CRS and represent the use of worked-out mines as greenhouses and the integration of IoT, machine learning, and neural networks, offer practical solutions to enhance reforestation efforts in the Kuznetsk Basin. Less energy is spent on maintaining microclimatic conditions, and the cost of transporting seedlings to the landing site is reduced. In addition, the use of the IoT, machine learning, and NN will automate the process of growing seedlings, reducing human participation in this process, as well as the risk of loss of planting material. Many technologies of the 21st century are just beginning to take part in solving the problems of reforestation, but it is already obvious that this will satisfy the need for planting material in areas with disturbed forests. These innovations can reduce the cost of transportation, minimize energy consumption, and increase planting material survival rates. By implementing these advancements, we can address environmental challenges, promote sustainable reclamation of disturbed lands, and contribute to a healthier ecosystem in the region.

***Authors' contribution statement*:** All authors equally contributed to this study.

***Conflict of interest*:** There is no conflict of interest to declare.

***Funding*:** The work was carried out within the framework of Decree No. 1144-r of the Government of the Russian Federation dated 11.05.2022, a comprehensive scientific and technical program of a full innovation cycle "Development and implementation of a complex of technologies in the fields of exploration and extraction of solid minerals, industrial safety, bioremediation, creation of new products of deep processing from coal raw materials with a consistent reduction of the environmental burden on the environment environment and risks to the life of the population" ("Clean coal – green Kuzbass"), action item 3.1 "Ecopolygon of world-class technologies of reclamation and remediation" (Agreement No. 075-15-2022-1200 dated 28.09.2022).

REFERENCES

Ajagekar, A., N.S. Mattsonb and F. You. 2023. Energy-efficient AI-based control of semi-closed greenhouses leveraging robust optimization in deep reinforcement learning. Advances in Applied Energy 9:100119.

Akhmetov, R., D. Dosmanbetov, A. Rakhimzhanov. B. Mambetov, A. Utebekova, Z. Rakymbekov, B. Maisupova and B. Yessimbek. 2023. Growth and development of the Black Saxaul depending on tillage in arid conditions of Kazakhstan. OnLine Journal of Biological Sciences 23:380-388.

Bashan, Y., L.E. de-Boshan, S.R. Prabhu and J. Hernandez. 2014. Advances in plant growth-promoting bacterial inoculant technology: Formulations and practical perspectives (1998–2013). Plant Soil 378:1-33.

Bugubaeva, A., A. Kuprijanov, V. Chashkov, S. Kuanyshbaev, K. Valiev, S. Mamikhin, A. Shcheglov, A. Nugmanov, A. Bulaev, G. Sultangazina, K. Kunanbayev, O. Chernyavskaya, G. Baubekova, G. Ruchkina, O. Safronova, M. Uxikbayeva and Y. Sokharev. 2023. Productivity assessment of various plant communities at uranium mine sites in Central Kazakhstan. SABRAO Journal of Breeding and Genetics 55:864-876. http://doi.org/10.54910/sabrao2023.55.3.21

Chernodubov, A.I., V.V. Malyshev, A.I. Zhurikhin and T.E. Galdina. 2013. Lesnye Kultury. Lesnoe Semennoe Delo:

Uchebnoe Posobie [Forest Crops. Forest Seed Business: A Manual]. FGBOU VPO VGLTA, Voronezh, 95 p.

Chibrik, T.S. 2002. Osnovy Biologicheskoi Rekultivatsii: Uchebnoe Posobie [Basics of Biological Reclamation: A Manual]. Izd-vo Ural. un-ta, Ekaterinburg, 172 p.

Curtis, L.V. and B.S. David. 2003. Effect of planting depth on growth of open-rooted *Pinus elliottii* and *Pinus taeda* seedlings in the United States. Southern African Forestry Journal 198:63-73.

Douglass, F.J. and R.T. Vic. 2005. Fertilizer-induced changes in rhizosphere electrical conductivity: Relation to forest tree seedling root system growth and function. New Forests 30:147-166.

Halford, N. 2019. Legislation governing genetically modified (GM) and genome edited crops in Europe: The need for change. Journal of the Science of Food and Agriculture 99:8-12.

Jans-Singh, M., P. Fidler, R.M. Ward and R. Choudhary. 2019. Monitoring the performance of an underground hydroponic farm, pp. 133-141. In: International Conference on Smart Infrastructure and Construction 2019 (ICSIC), Cambridge, UK, 8-10 Jul. 2019. Churchill College, Cambridge.

Kharionovskii, A.A. and M.Yu. Danilova. 2017. Rekultivatsiya narushennykh zemel v ugolnoi promyshlennosti [Reclamation of disturbed lands in the coal industry]. Vestnik Nauchnogo tsentra 3:72-77.

Kondratenko, E.P. and O.M. Soboleva. 2023. Features of the development of the primary roots of wheat seedlings after the removal of abiotic electromagnetic stress. Journal of Global Innovations in Agricultural Sciences 11:127-133. https://doi.org/10.22194/JGIAS/23.1058

Korchagov, S.A., S.E. Gribov and O.Yu. Obryadina. 2017. Ekonomicheskaya otsenka sozdaniya lesnykh kultur razlichnym vidom posadochnogo materiala [Economic assessment of the creation of forest crops with various types of planting material]. Izvestiya VUZov. Lesnoi zhurnal 5:92-102.

Kuznetsova, L.V. 2008. Geotekhnologicheskii aspekt syrevogo potentSiala podzemnoi dobychi uglya v Kuzbasse [Geotechnological aspect of raw material potential of underground coal mining in Kuzbass]. Vestnik KuzGTU 3:6-9.

McGrath, D., J. Henry, R. Munroe and C. Williams. 2021. From propagation to field: Infuence of tray design on tree seedling quality and performance. Horticultural Research Institute 39:33-40.

Merzlenko, M.D. and N.A. Babich. 2011. Teoriya i Praktika Iskusstvennogo Lesovosstanovleniya: Uchebnoe Posobie [Theory and Practice of Artificial Reforestation: A Manual]. Severnyi (Arkticheskii) federalnyi universitet imeni M.V. Lomonosova, Arkhangelsk, pp.239 .

Mikhailova, A.I. 2008. Analiz sovremennoi situatsii v oblasti lesokhozyaistvennoi rekultivatsii otvalov gornykh porod [analysis of the current situation in the field of forestry reclamation of rock dumps]. Gornyy informatsionno-analiticheskiy byulleten.5:291-298.

Morkovina, S., O. Kunickaya, L. Dolmatova, O. Markov, V.L. Nguyen, T. Baranova, S. Shadrina and O. Grin'ko. 2021. Comparative analysis of economic aspects of growing seedlings with closed and open root systems: The experience of Russia. Asian Journal of Water, Environment and Pollution 18:19-26.

Naoshi, K. and K.C. Ting. 1998. Robotics for plant production. Artificial Intelligence Review 12:227-243.

Nokusheva, Z.A., E.Y. Kantarbayeva, M.B. Ormanbetov, B.T. Yermagambet, Z.M. Kassenova and M.K. Kazankapova. 2023. Development and implementation of effective schemes for the use of mineral fertilizers in the forest-steppe zone of the North Kazakhstan region. OnLine Journal of Biological Sciences 23:313-322.

Oliet, J.A., J. Puertolas, R. Planelles and D.F. Jacobs. 2013. Nutrient loading of forest tree seedlings to promote stress resistance and field performance: A Mediterranean perspective. New Forests 44:649-669.

Ospangaliyev, A., A. Utebekova, D. Dosmanbetov, R. Akhmetov and K. Mazarzhanova. 2022. Impact of urban landscaping on improving the sustainable development of the urban environment. The case of Nur-Sultan. Journal of Environmental Management and Tourism 5:1457-1464. https://doi.org/10.14505/jemt.v13.5(61).21

Ospangaliyev, A., D. Sarsekova, K. Mazarzhanova, D. Dosmanbetov, A. Kopabayeva, E. Obezinskaya, A. Nurlabi and B. Mukanov. 2023. Assessment of the degree of landscaping in Astana, Kazakhstan, and recommendations for its development. Caspian Journal of Environmental Sciences 21:585-594.

Potapov, V.P., V.P. Mazikin, E.L. Schastlivtsev and N.Yu. Vashlaeva. 2005. Geoekologiya Ugledobyvayushchikh Raionov Kuzbassa [Geoecology of Coal Mining Areas of Kuzbass]. Nauka. Sib. otd-nie, Novosibirsk, 660 p.

Prokazin, N.E., S.A. Rodin, V.I. Kazakov, E.N. Lobanova and I.V. Kazakov. 2019. Sovershenstvovanie tekhnologii vyrashchivaniya posadochnogo materiala i lesovosstanovleniya na gorelnikakh [Improving technologies for growing planting material and reforestation in burnt areas]. Lesokhoz. informatsiya: Elektron. setevoi zhurnal 3:38-47.

Rakymbekov, Z., K. Abayeva, D. Dosmanbetov, R. Akhmetov and M. Shynybekov. 2023. Relationship between laboratory germination and biometric parameters of *Betula jarmolenkoana Golosk*. Aglets. OnLine Journal of Biological Sciences 23:117-123. https://doi.org/10.3844/ojbsci.2023.117.123

Ren, Y.Z., M.J. Wang, *I.A. Saeeda, X. Chen and W. Gao*. 2018. Progress, problems and prospects for standardization of greenhouse-related technologies.

International Journal of Agricultural and Biological Engineering 11:40-48.

Revyako, L.I. 2013. Lesnye Kultury. Proektirovanie i Sozdanie Lesnykh Nasazhdenii: Uchebnoe Posobie dlya stud. napravleniya 250100.62 – "Lesnoe delo" [Forest Crops. Design and Creation of Forest Plantations: A Manual for Students of Program 250100.62 – "Forestry"]. Novocherk. gos. melior. akad., kaf. LK i LPKh, Novocherkassk, pp.s 167.

Rodin, A.R., E.A. Kalashnikova, P.A. Rodin and G.V. Silaev. 2009. Lesnye Kultury [Forest Crops], 2nd ed. Vektor TiS, N. Novgorod, pp. 466

Tretyakova, R.A., O.V. Parkina, O.E. Yakubenko and A.A. Yakubenko. 2023. Biometricheskie pokazateli sazhentsev khvoinykh porod s otkrytoi i zakrytoi kornevoi sistemoi [Biometric indicators of coniferous seedlings with open and closed root systems]. Lesokhozyaistvennaya informatsiya 2:136-145.

Ufimtsev, V.I. 2017. Opyt i sovremennoe sostoyanie lesnoi rekultivatsii v Kuzbasse [Experience and current state of forest reclamation in Kuzbass]. Sibirskii lesnoi zhurnal 4:12-27.

Vicent, A., D.J. Iglesias, J. Jacas, E. Primo-Millo, M. Talon and A. G´omez-Cadenas. 2005. Hydrogel substrate amendment alleviates drought effects on young citrus plants. Plant and Soil 270:73-82.

Yakimov, N.I., V.K. Gvozdev and A.N. Prakhodskii. 2007. Lesnye Kultury i Zashchitnoe Lesorazvedenie [Forest Crops and Protective Afforestation]. BGTU, Minsk, pp. 312

Yessimbek, B., B. Mambetov, R. Akhmetov, D. Dosmanbetov, K. Abayeva, A. Kozhabekova, A. Oraikhanova and M. Baibatshanov. 2022. Prevention of desertification and land degradation using Black Saxaul in arid conditions. OnLine Journal of Biological Sciences 22:484-491. https://doi.org/10.3844/ojbsci.2022.484.491

Zaushintsena, A.V. and N.V. Kozhevnikov. 2015. Biorekultivatsionnoe raionirovanie Kuzbassa [Bioreclamation zoning of Kuzbass]. Vestnik KemGU 1-2:20-25.

Zharikov, V.P. 2012. Rekultivatsiya gidrootvalov vskryshnykh porod na razrezakh Kuzbassa [Reclamation of hydraulic dumps of overburden rocks in open-pit mines of Kuzbass]. Gornyi informatsionno-analiticheskii byulleten (nauchno-tekhnicheskii zhurnal) 1:42-47.